



Jet Surface Interaction

Scrubbing Noise from High Aspect-Ratio Rectangular Jets

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FW Projects

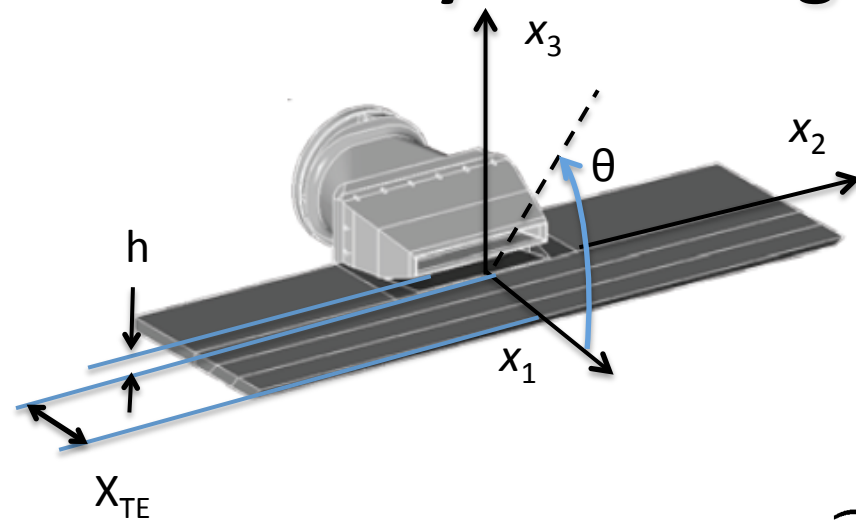
Motivation

Interaction of jet exhaust with nearby solid surfaces:

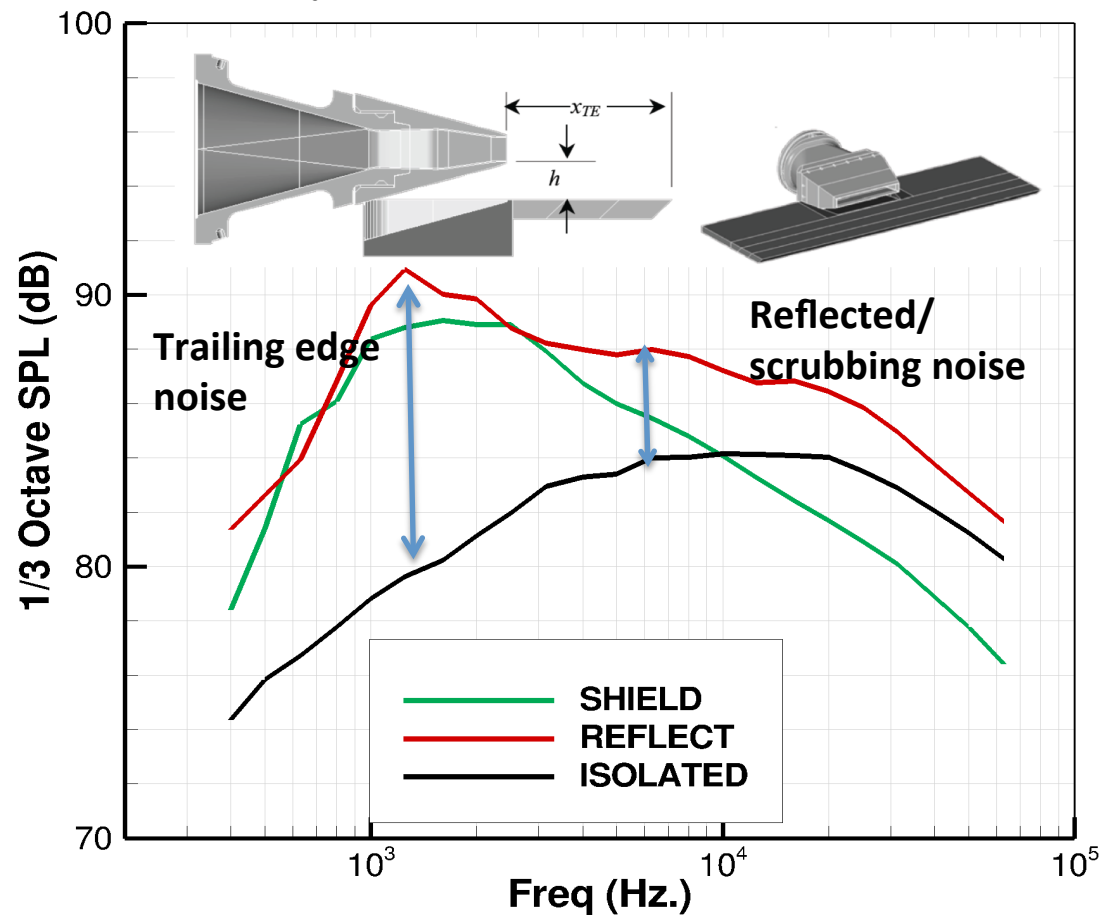
- Hybrid Wing Body (HWB) concepts
- High aspect ratio rectangular exhaust with extended beveled surfaces
- Over the wing engine mount
- Nearby structural components could provide noise shielding
- They could also produce new sources of sound



Geometry – Rectangular Exhaust



$$M_a = 0.90, h = 0, X_{TE} = 12'', \theta = \pi/2$$



* J. Bridges, AIAA-2014-0876

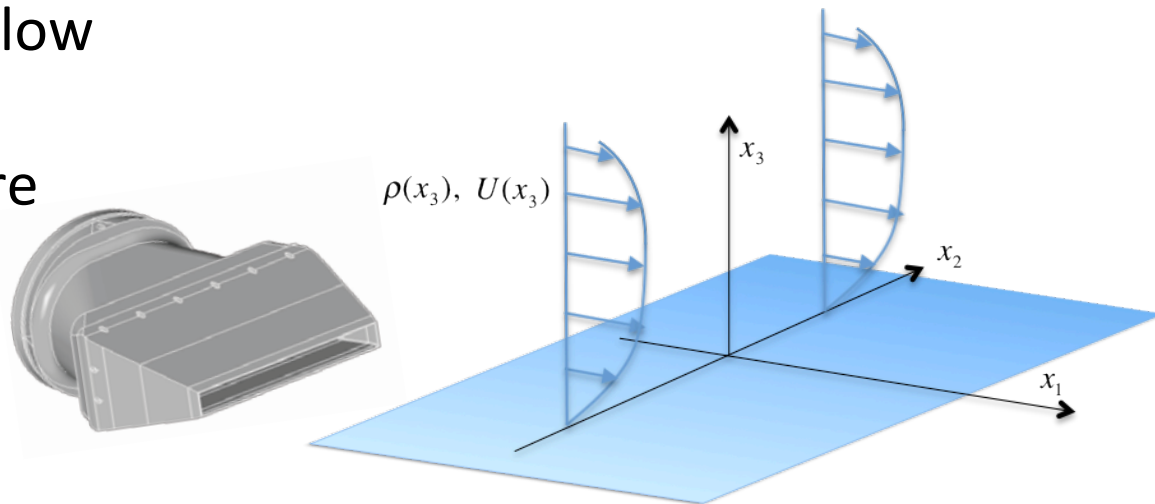


Outline

- Governing Equations
- Propagation Green's Fun (GF) in High-AR Rectangular Jets
- Sample GF - 8:1 Aspect Ratio Jet Exhaust
- Scrubbing Noise Spectra and Data Comparison
- Summary

Scrubbing Noise

- NS Equations \rightarrow (Mean Flow + Linear Fluctuations)
- Locally Parallel Mean Flow
- Compressible
- Constant Static Pressure
- Ideal Gas Law



Variable density Pridmore-Brown eq.

$$L\pi' = \Gamma, \quad \pi' \simeq \frac{p'(\vec{x}, t)}{\gamma \bar{p}} \quad (\text{Goldstein 2010})$$

$$L \equiv D \left(D^2 - \frac{\partial}{\partial x_j} \left(c^2 \frac{\partial}{\partial x_j} \right) \right) + 2c^2 \frac{\partial U}{\partial x_j} \frac{\partial^2}{\partial x_1 \partial x_j}, \quad D \equiv \frac{\partial}{\partial t} + U \frac{\partial}{\partial x_1}$$

Green's Function Method

$$\pi'(\vec{x}, t) = \int \int_{\vec{y} \tau} G(\vec{x}, t; \vec{y}, \tau) \Gamma(\vec{y}, \tau) d\tau d\vec{y}$$

$$LG(\vec{x}, t; \vec{y}, \tau) = \delta(\vec{x} - \vec{y}) \delta(t - \tau)$$

- **Wetted side of the plate only**

(Trailing Edge Noise component discussed by Goldstein *et al*, 2013)

Transform: $(x_1 - y_1, x_2 - y_2, t - \tau) \rightarrow (k_1, k_2, \omega)$

$$G(\vec{x}, t; \vec{y}, \tau) \rightarrow \hat{G}(\vec{k}_t, x_3; y_3, \omega) \quad \vec{k}_t \equiv (k_1, k_2)$$

- **Far-field Spectrum**

$$\overline{p^2}(\vec{x}, \omega) = \int \int_{\vec{y} \xi} \int_{\tau=-\infty}^{\infty} \mathbf{G}^*(\vec{x}, \vec{y} - \vec{\xi}/2; \omega) \mathbf{G}(\vec{x}, \vec{y} + \vec{\xi}/2; \omega) q(\vec{y}, \vec{\xi}, \tau) e^{i\omega\tau} d\tau d\vec{\xi} d\vec{y}$$

GF Method (Cont'd)



- Stationary Phase solution ($\kappa_o R \gg 1$, $\kappa_o = \omega / c_\infty$)

$$\vec{k}_t^s = \kappa_o (\sin \phi^s \cos \theta^s, \cos \phi^s)$$

(Khavaran, 2014)

$$\mathbf{G}(\vec{x}, \vec{y}; \omega) \sim -i \frac{e^{i\Theta(\vec{k}_t^s, \vec{x}, \omega)}}{(2\pi)^3 R} \frac{\sin \theta^s \sin^2 \phi^s}{c_\infty^2 c(y_3)} \frac{b_2(\vec{k}_t^s, \omega) V_1(\vec{k}_t^s, y_3, \omega)}{W_o(\vec{k}_t^s, \omega, \vec{Z})} \frac{(1 - M_\infty \sin \phi^s \cos \theta^s) \Im}{\left(1 - \frac{U(y_3)}{c_\infty} \sin \phi^s \cos \theta^s\right)^2}$$

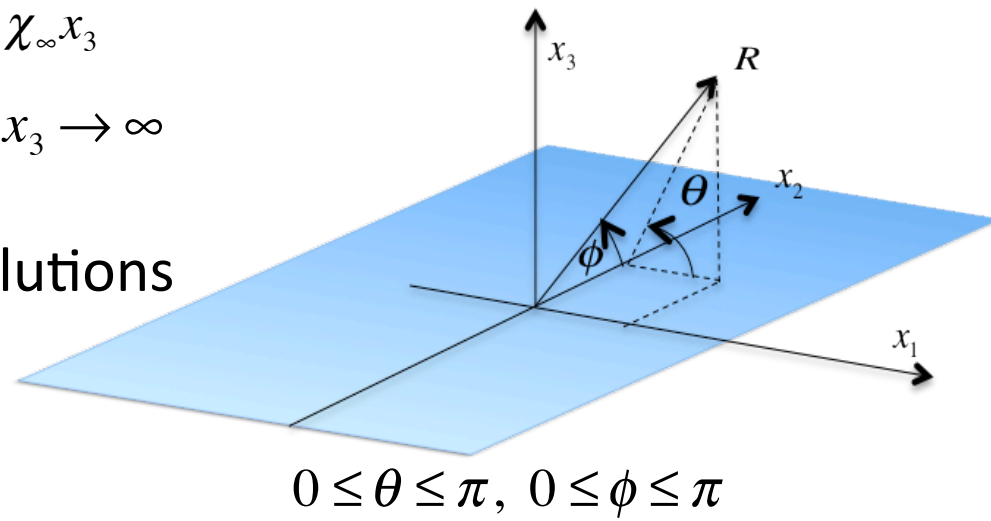
$$\Theta(\vec{k}_t, \vec{x}, \omega) = k_1(x_1 - y_1) + k_2(x_2 - y_2) - \chi_\infty x_3$$

$$V_2(\vec{k}_t, x_3, \omega) = b_2(\vec{k}_t, \omega) e^{-i\chi_\infty x_3} \quad x_3 \rightarrow \infty$$

- Two linearly independent solutions

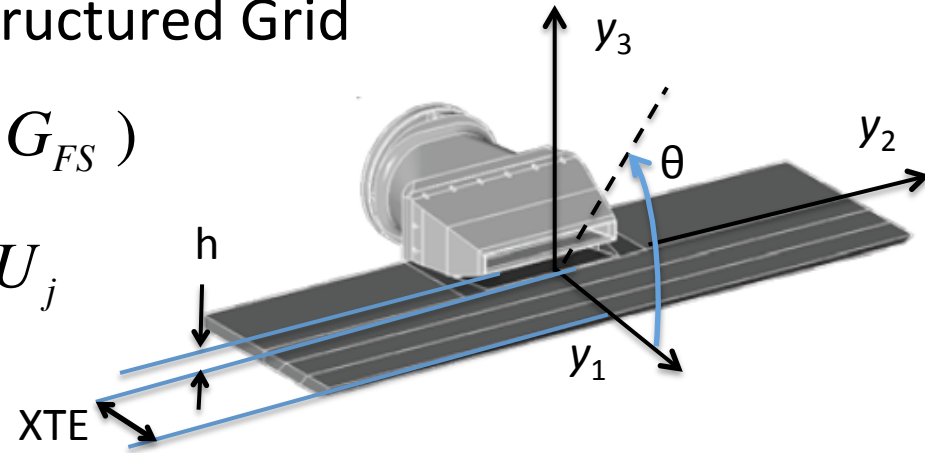
$$V_j(\vec{k}_t, x_3, \omega), \quad j = 1, 2$$

$$V_j'' + f(\vec{k}_t, x_3, \omega) V_j = 0$$



Numerical Results

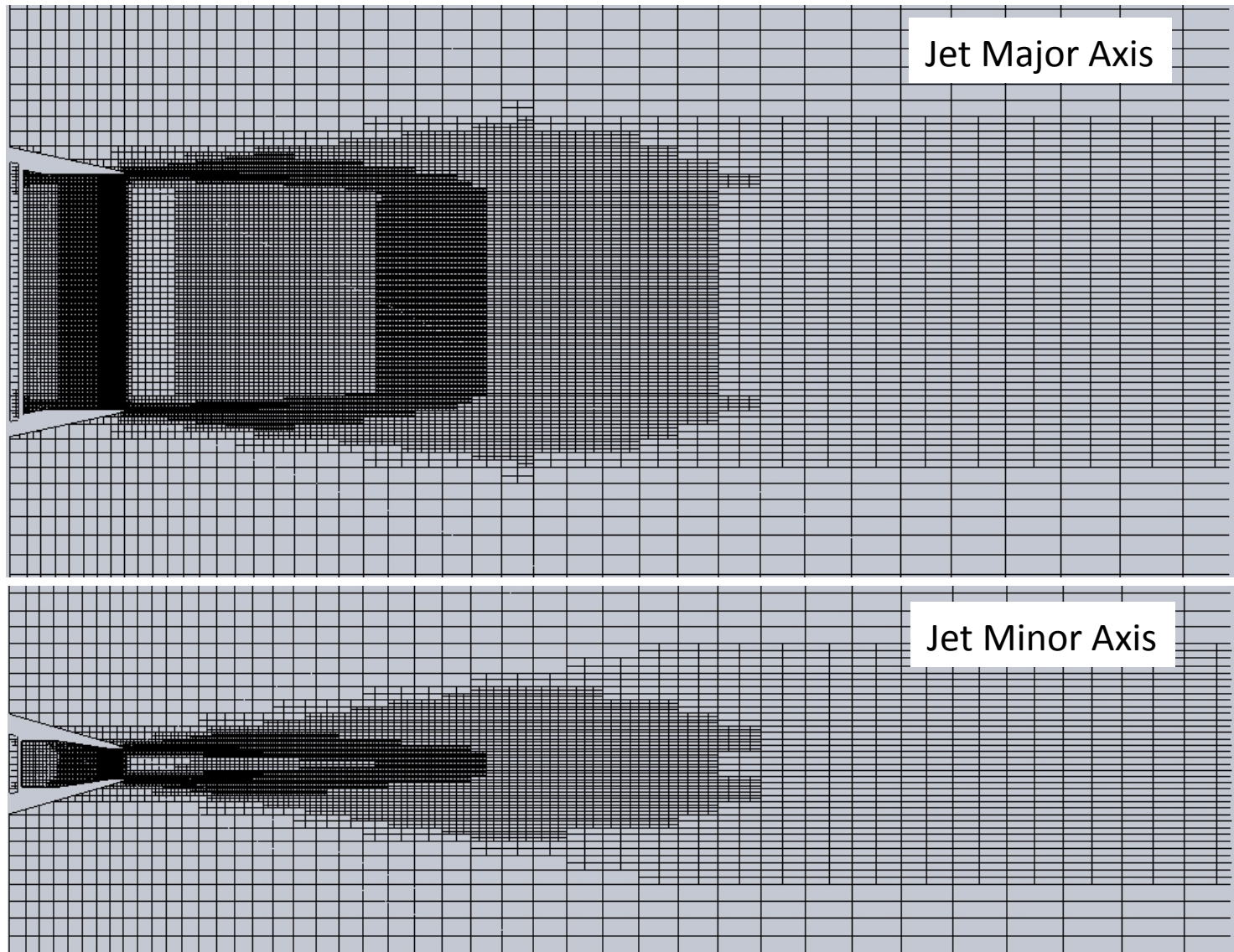
- SolidWorks RANS (k- ϵ Turb Model) – Commercial Code
- Mapping – Cloud Solution to Structured Grid
- Normalized GF $G_N \equiv \pi c_\infty^3 (\mathbf{G} / G_{FS})$
- Strouhal Frequency $St \equiv a f / U_j$
- Source Location $\eta \equiv y_3 / a$



Simulation Conditions

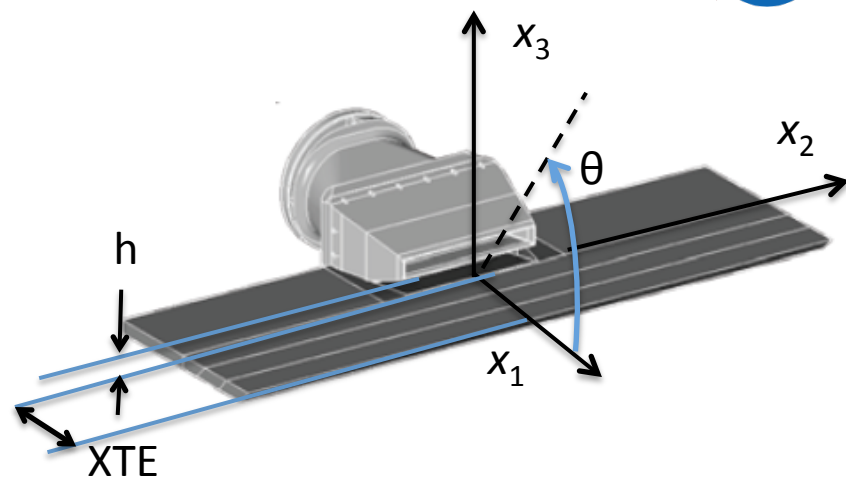
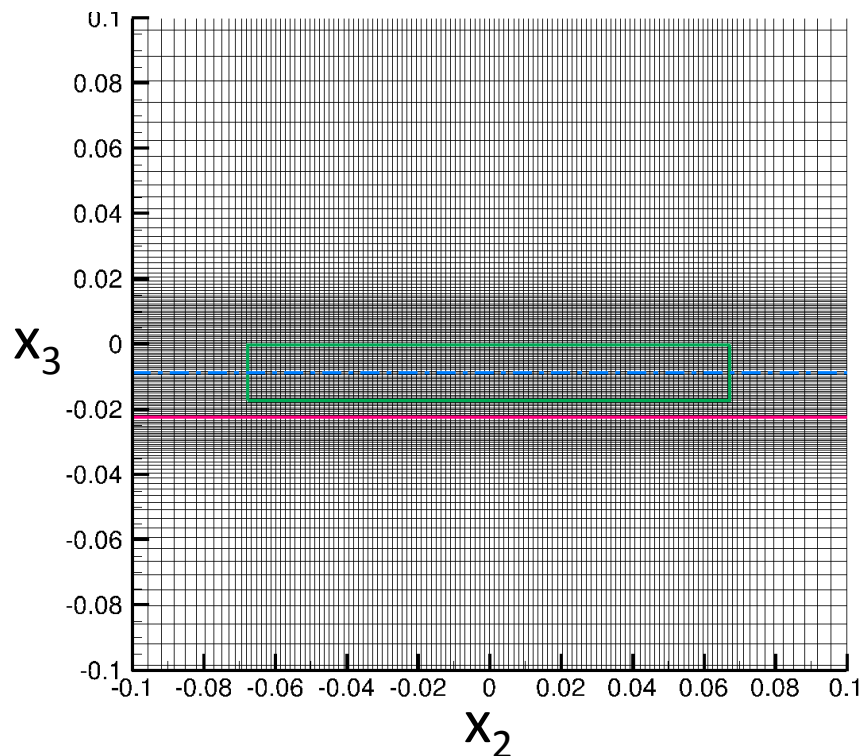
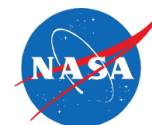
8:1 Aspect Ratio Rectangular Exhaust (N8Z)					
Set Point	Standoff h (in)	XTE (in)	NPR	NTR	M _j
SP07 (H02XTE12)	0.20	12	1.86	1.0	0.98
SP07 (H19XTE12)	1.90	12	1.86	1.0	0.98
SP07 (Isolated)	NA	NA	1.86	1.0	0.98
SP05 (H19XTE12)	1.90	12	1.42	1.0	0.72
SP03 (H19XTE12)	1.90	12	1.19	1.0	0.51

SolidWorks Mesh* – N8Z



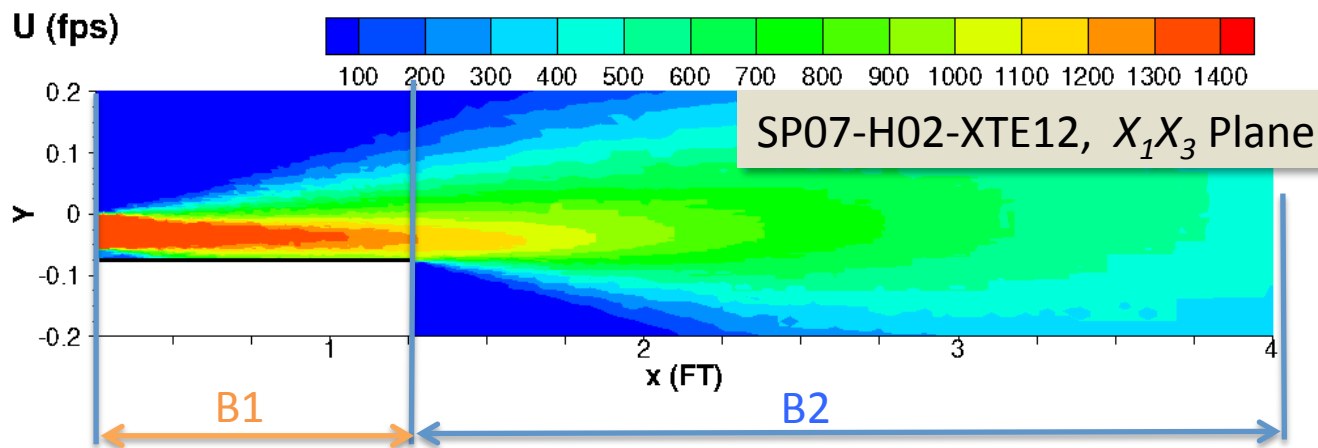
* Rick Bozak, 2013

RANS Solution (Mapped to Rectangular Grid)

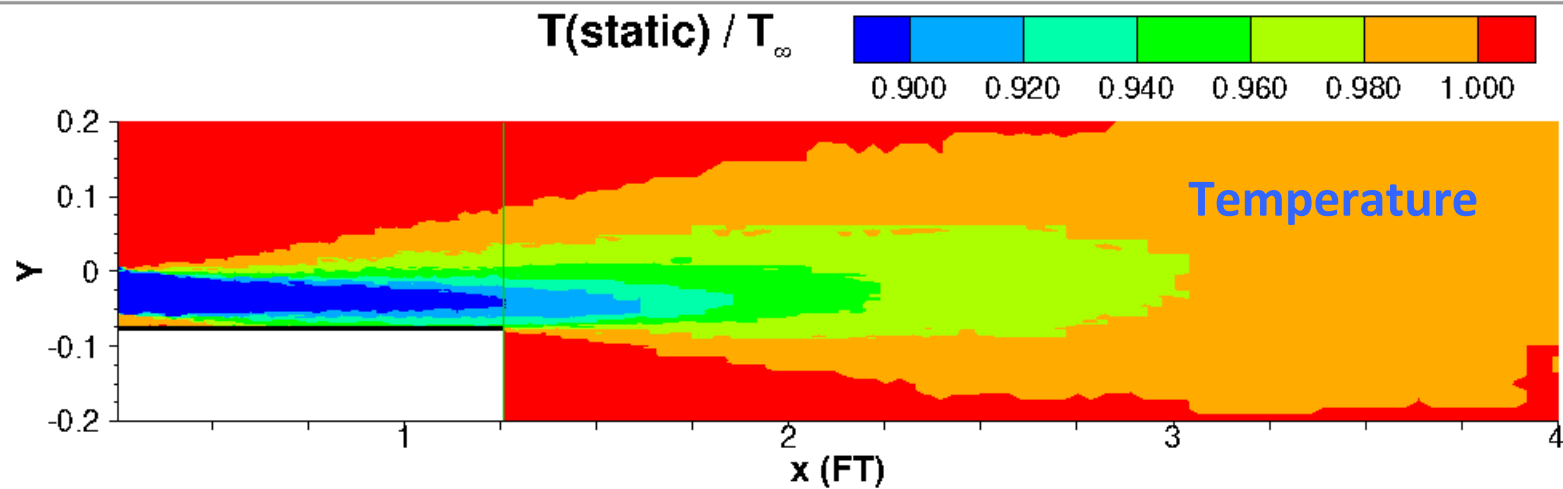
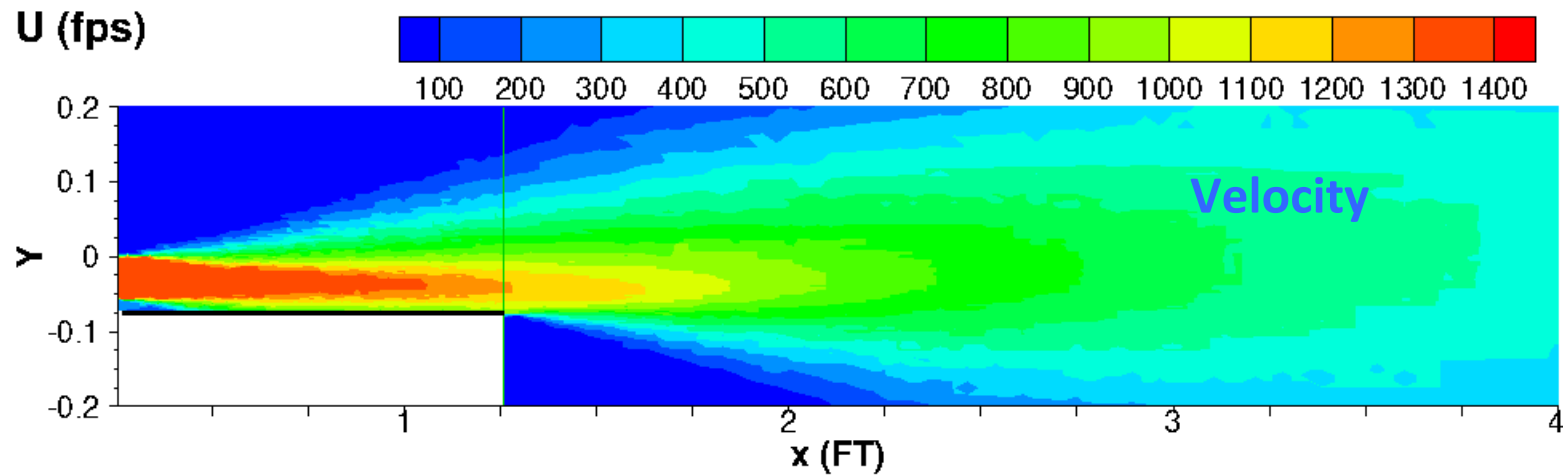


Block1: 70 171 109 (x_1, x_2, x_3)

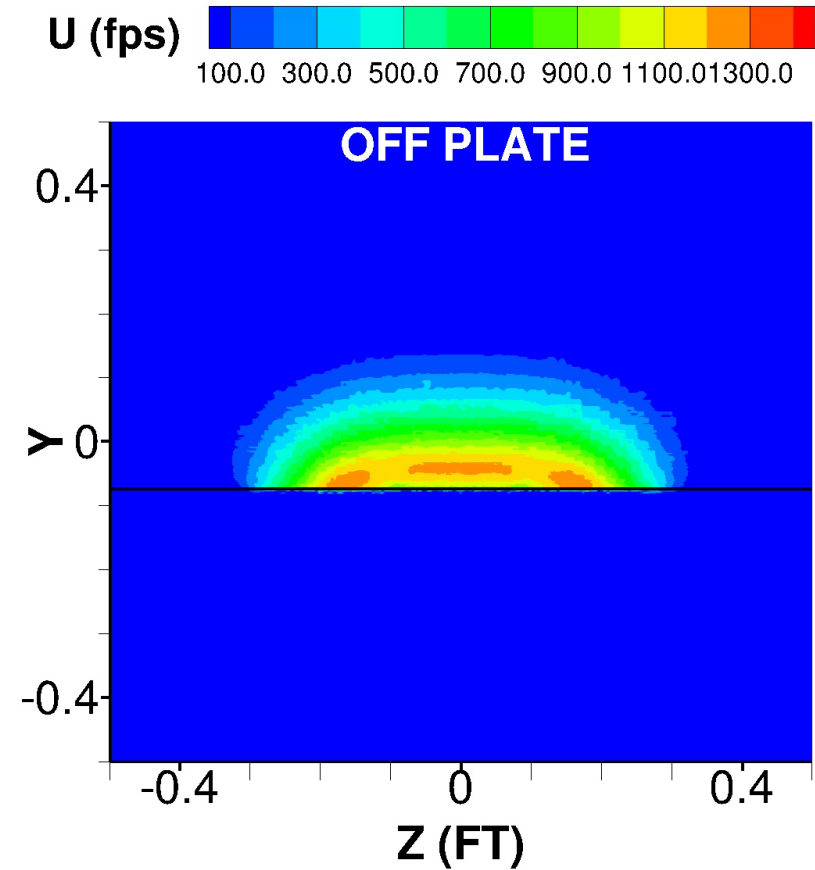
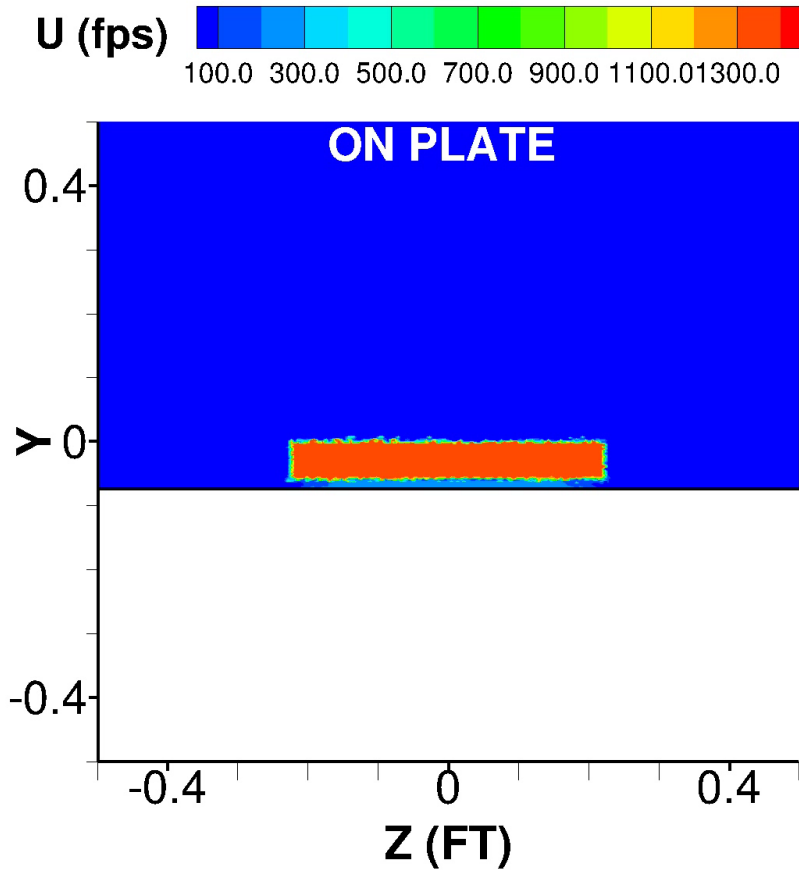
Block2: 81 171 169



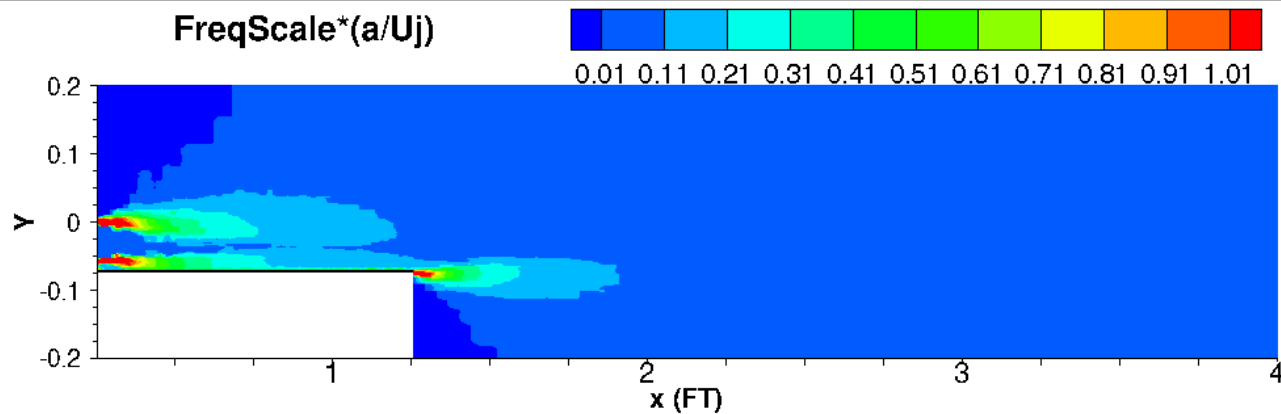
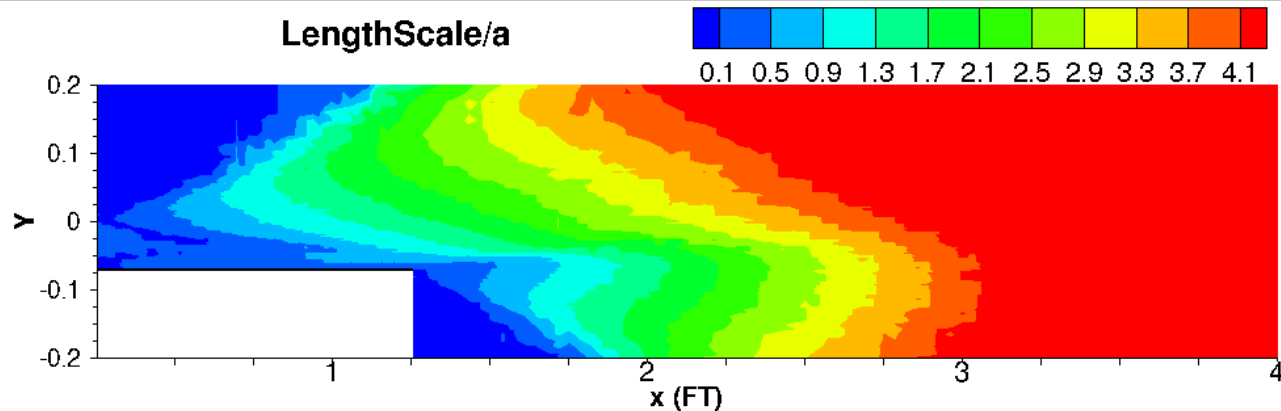
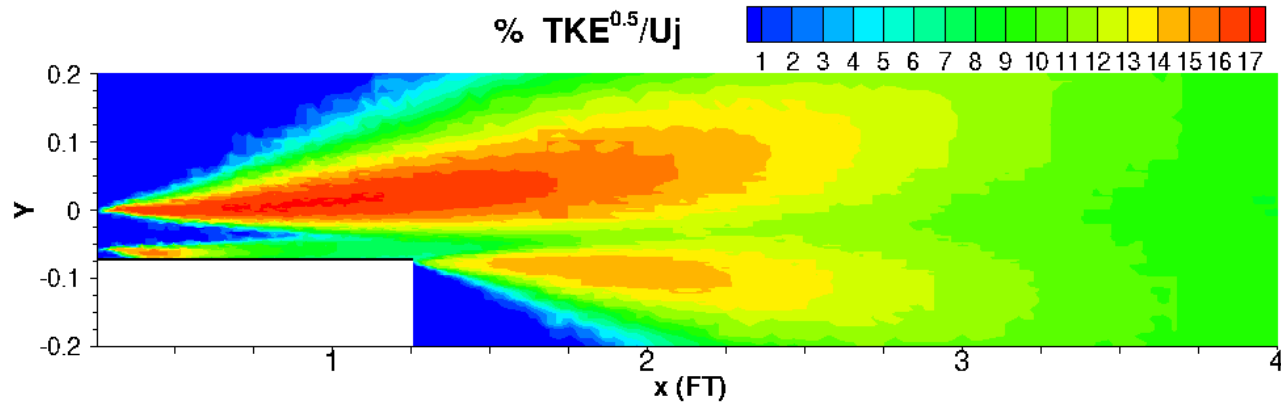
Mean Flow (SP07-H02-XTE12)



Mean Axial Velocity (SP07-H02-XTE12)



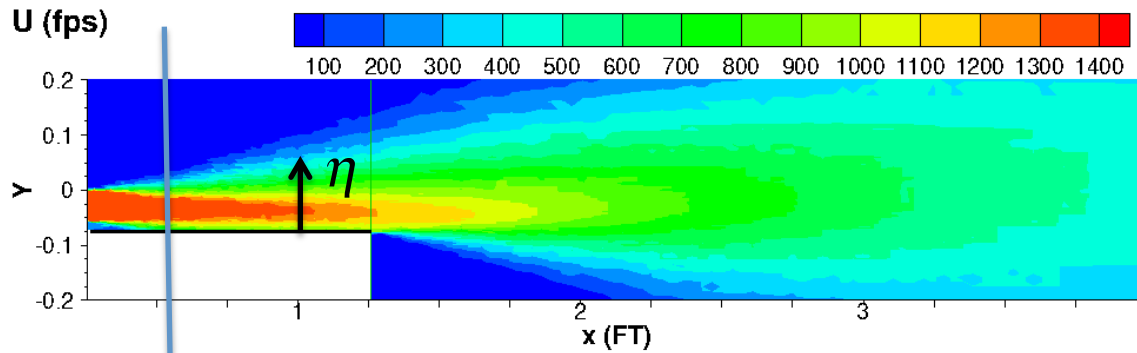
Turbulence (SP07-H02-XTE12)



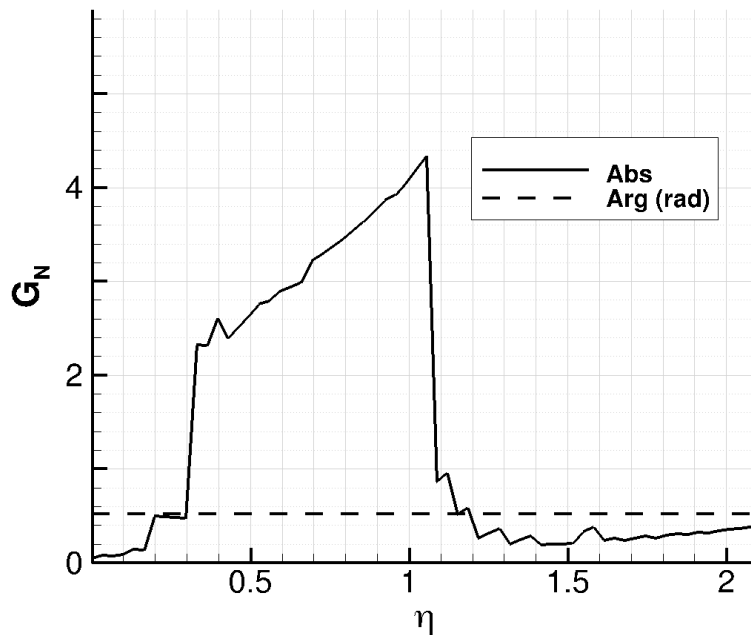
G_N – Above Surface

N8Z – SP07-H02-XTE12

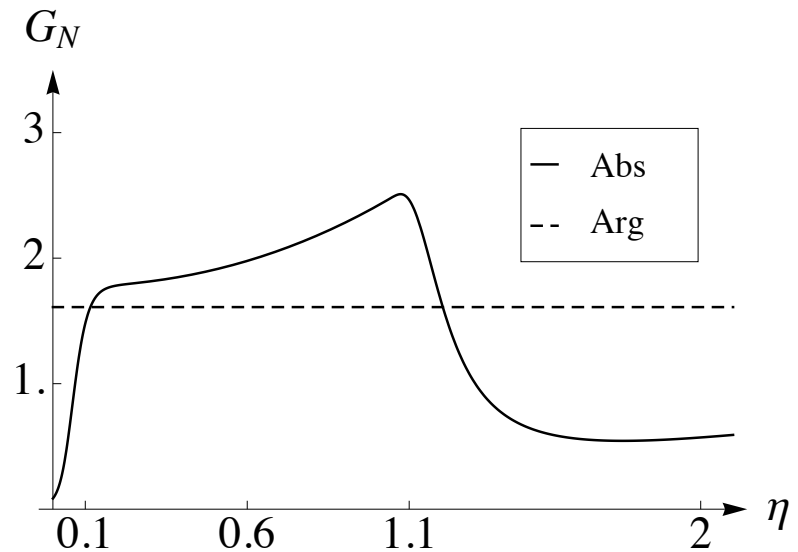
($\theta = \pi / 4, St = 0.25$)



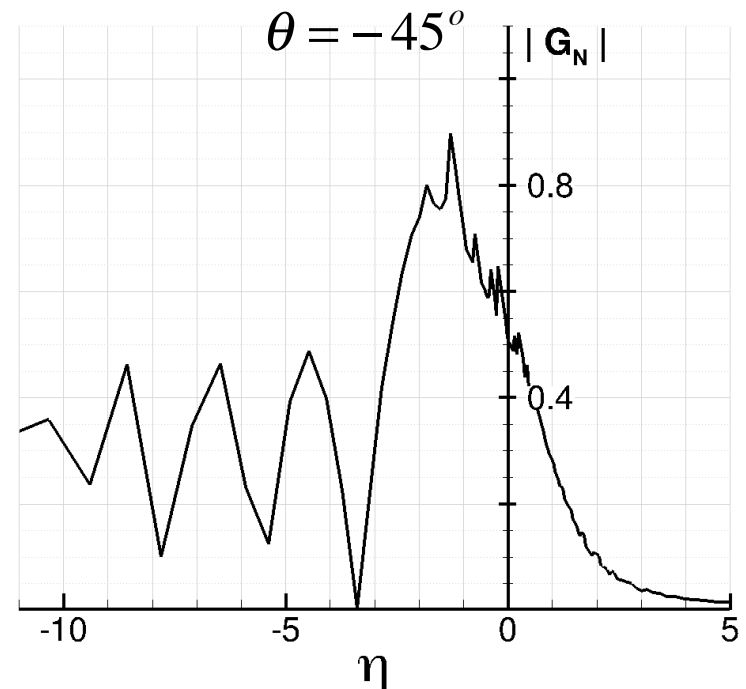
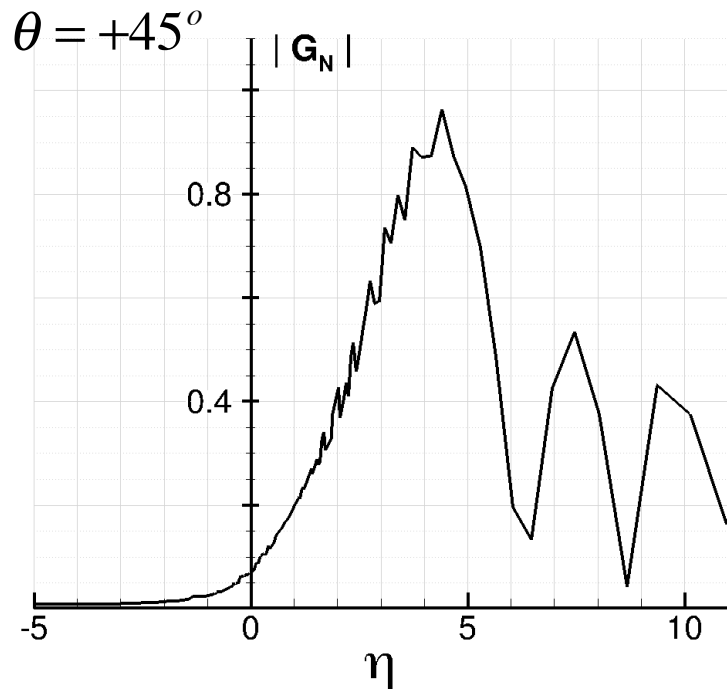
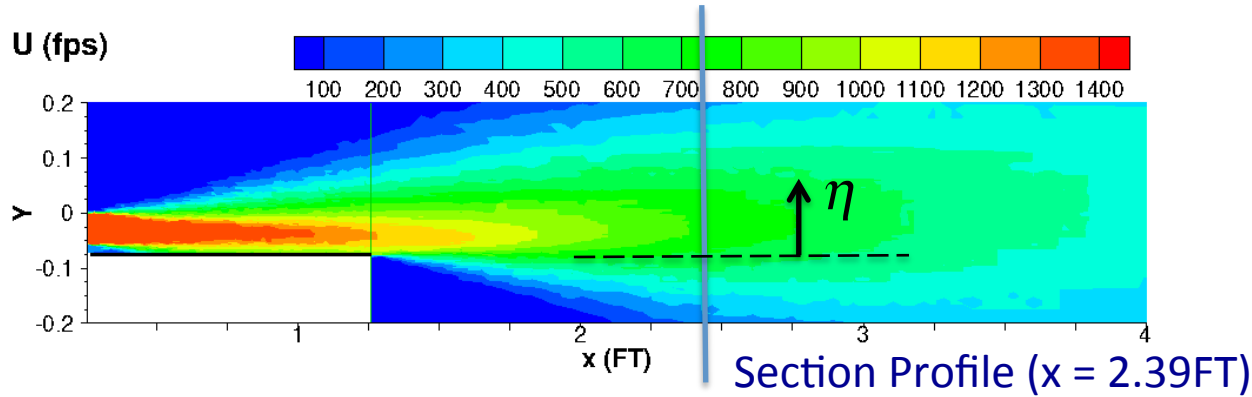
Section Profile ($x = 0.52\text{FT}$)



(G_N – Analytical Profile)



G_N – Downstream the Plate ($\theta = \pm\pi/4, St = 0.25$)

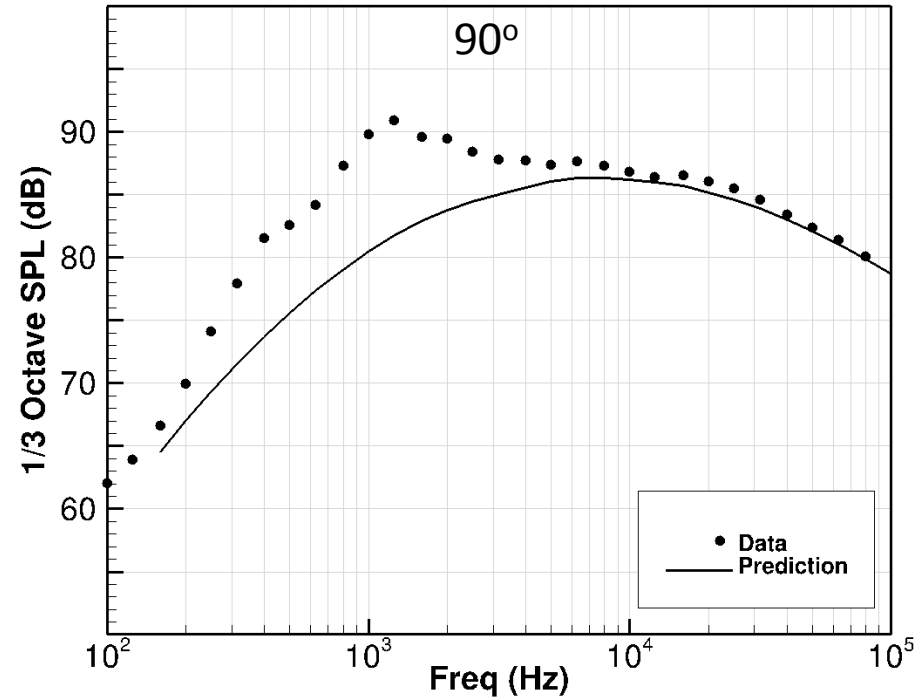
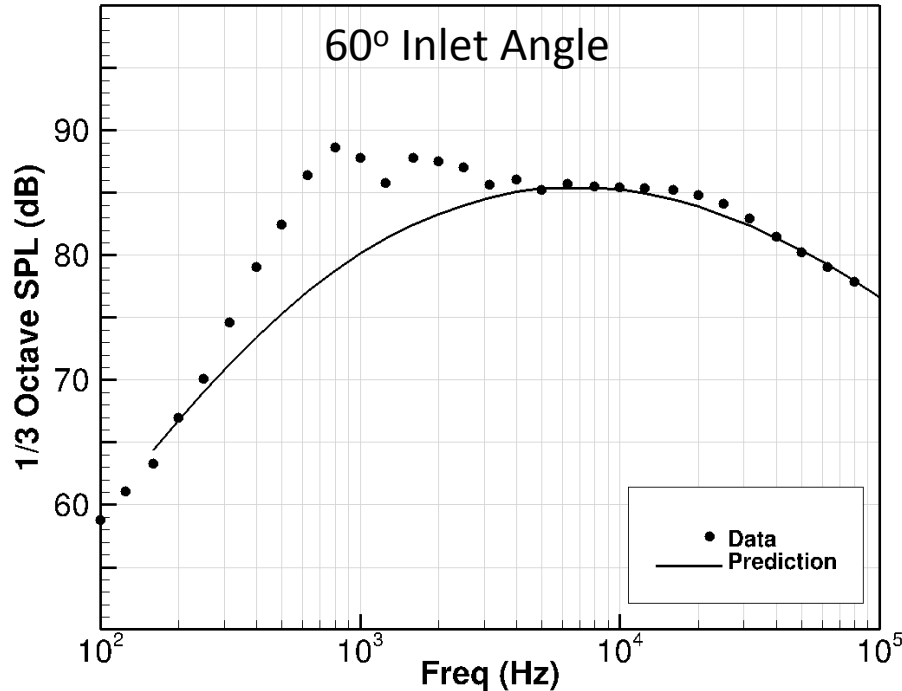


Sample Results



(1/3 Octave Lossless Spectra, Arc = 100D_{eq})

N8Z – SP07-H02-XTE12

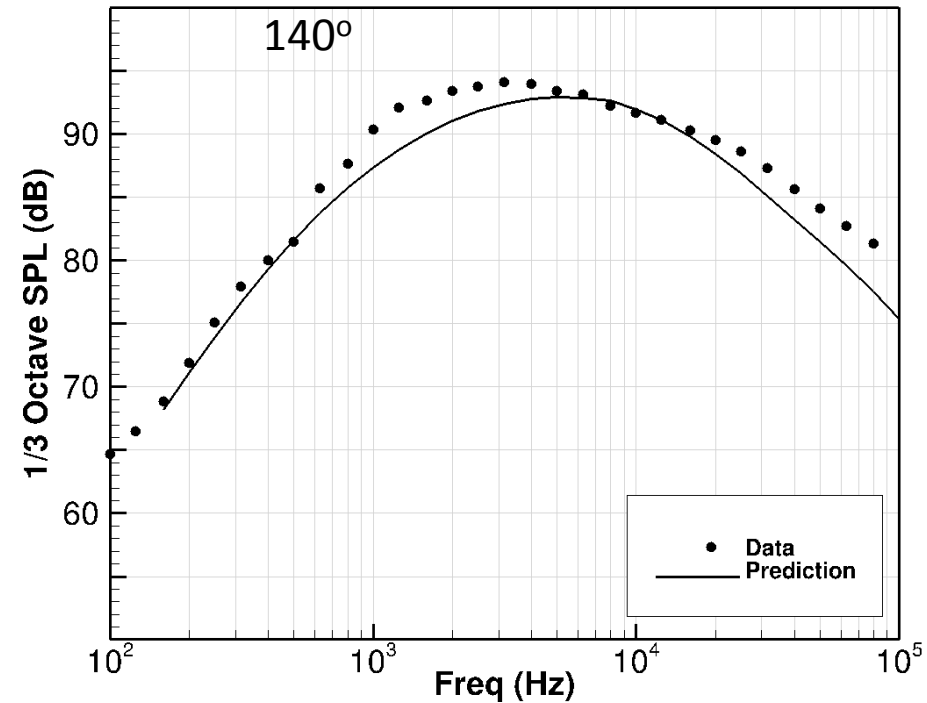
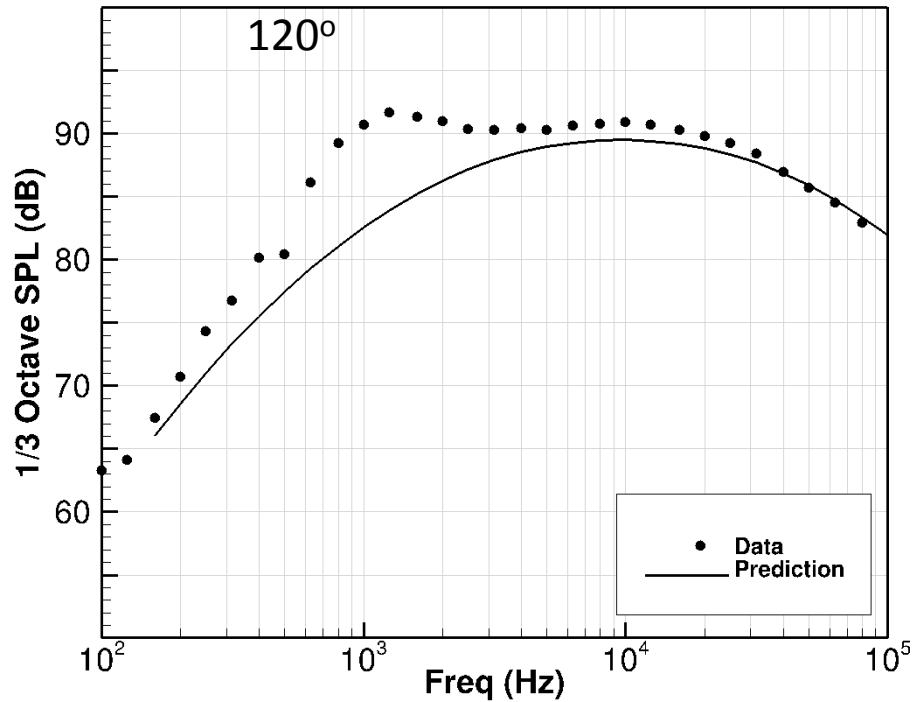


N8Z-SP07-H02X12, Inlet Angle = 60 deg
(CL, CT) = (0.74, 0.93), (Am, Bm) = (4.727, 4.379), JSIT VER-5T
Arc = 17.75FT, LOSSLESS

* Measured Spectra, C. Brown & J. Bridges, GRC

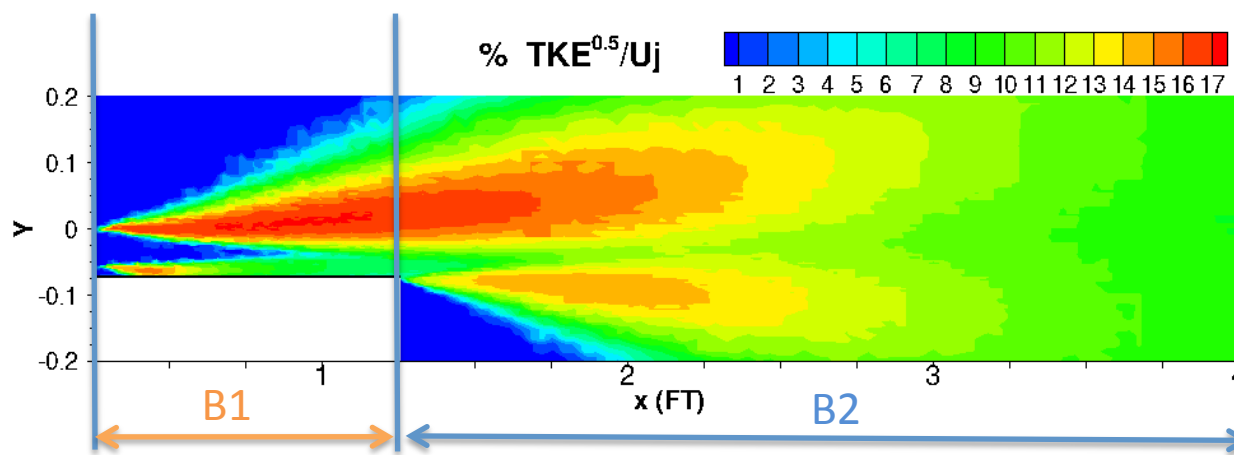
Sample Results (Cont'd)

N8Z – SP07-H02-XTE12

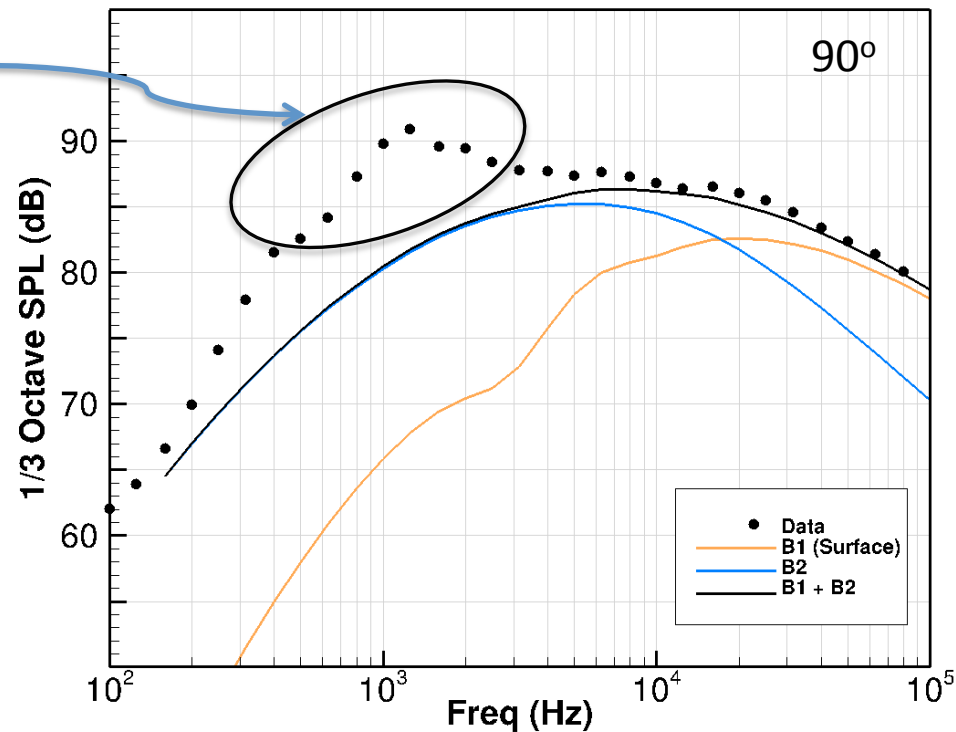


Sample Results (Cont'd)

N8Z – SP07-H02-XTE12

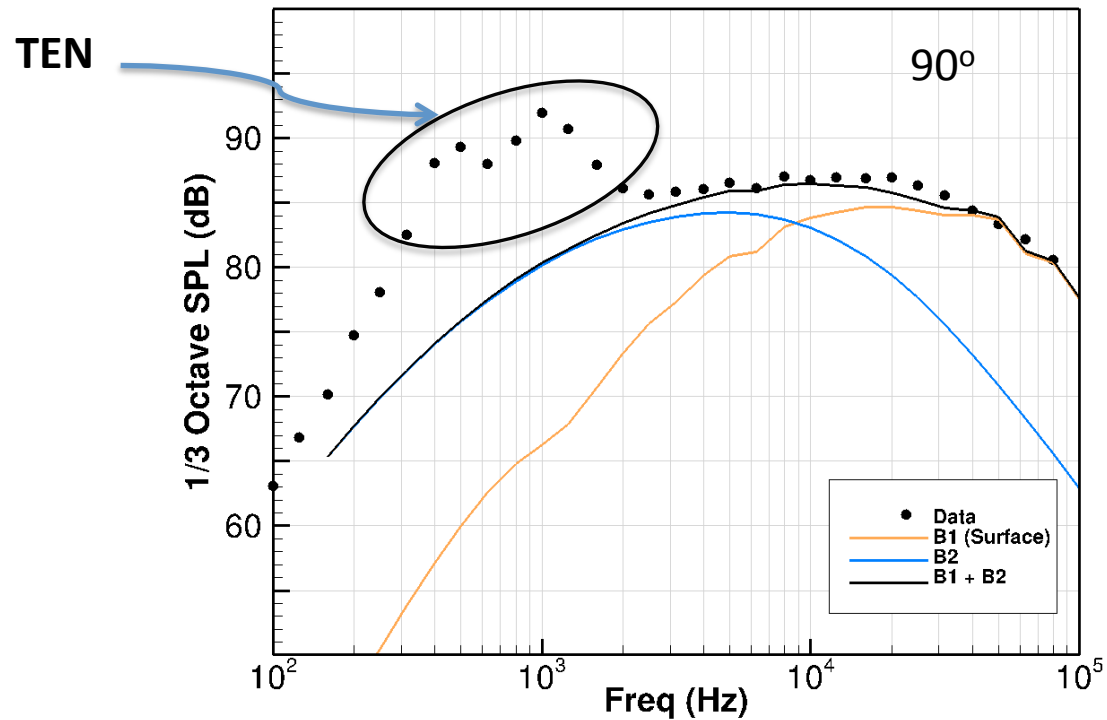
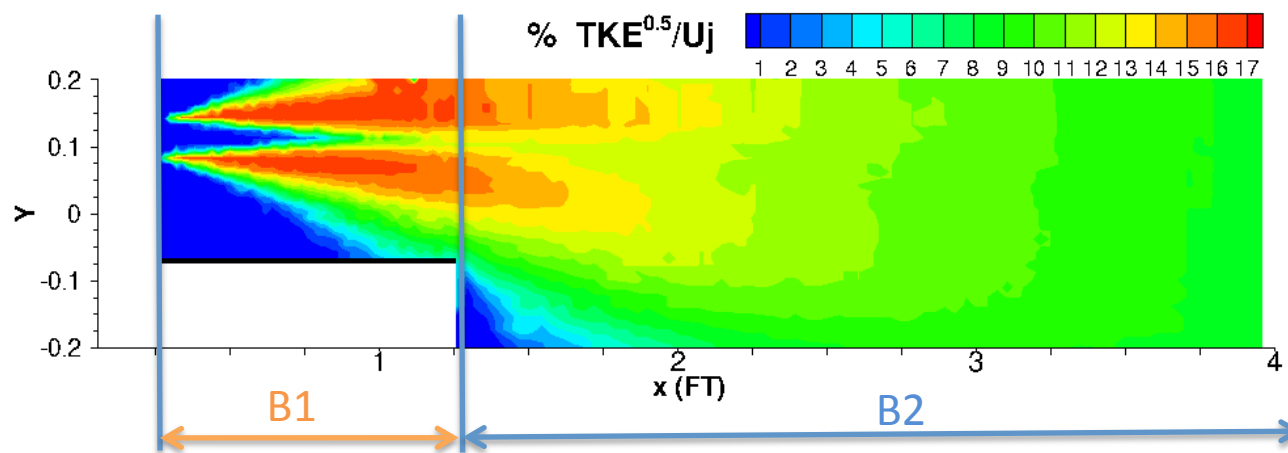


Trailing Edge Noise



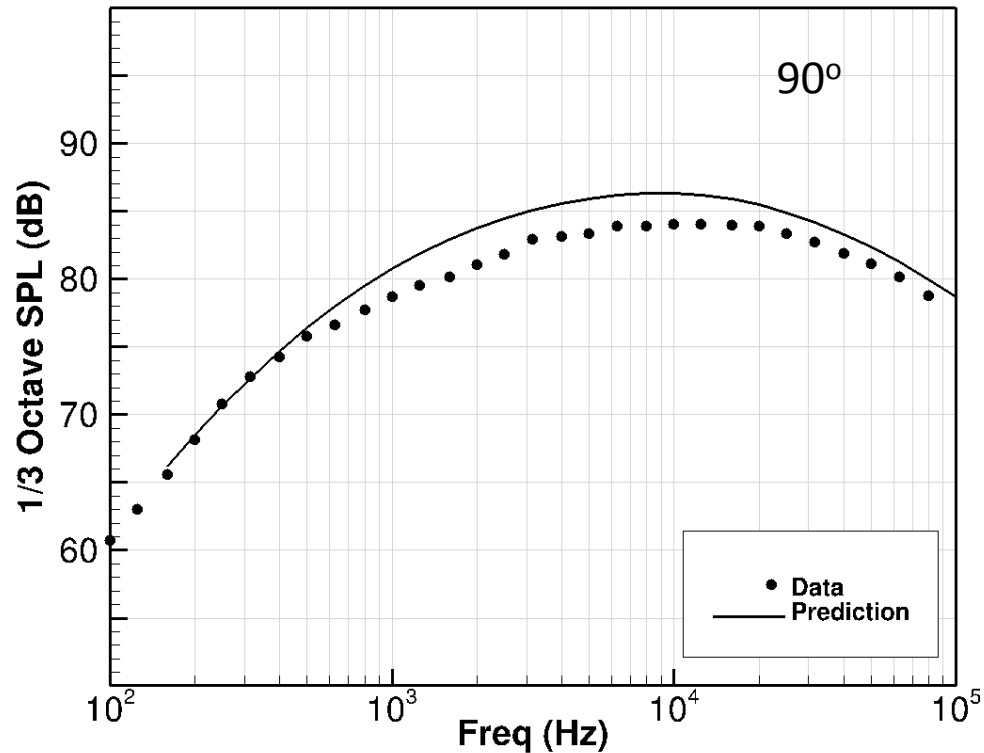
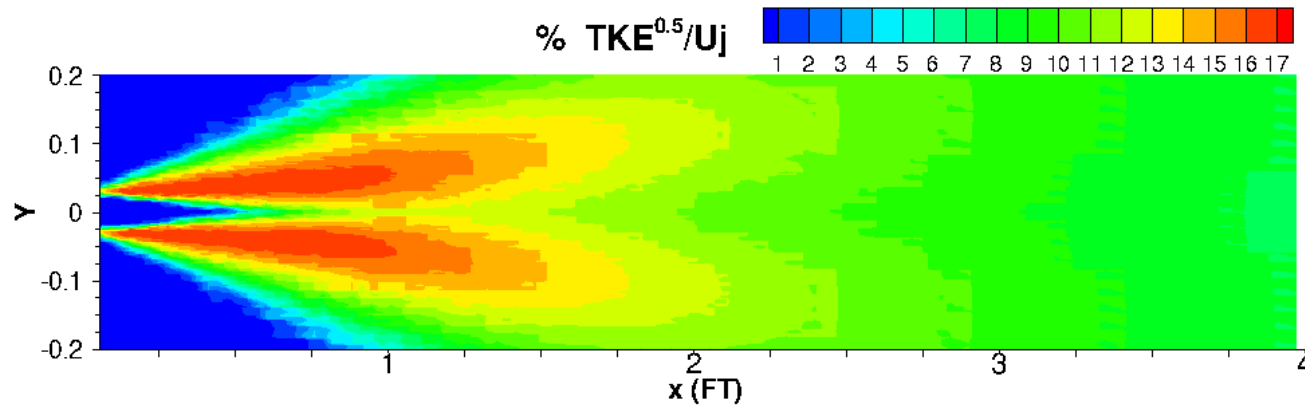
Sample Results (Cont'd)

N8Z – SP07-H19-XTE12



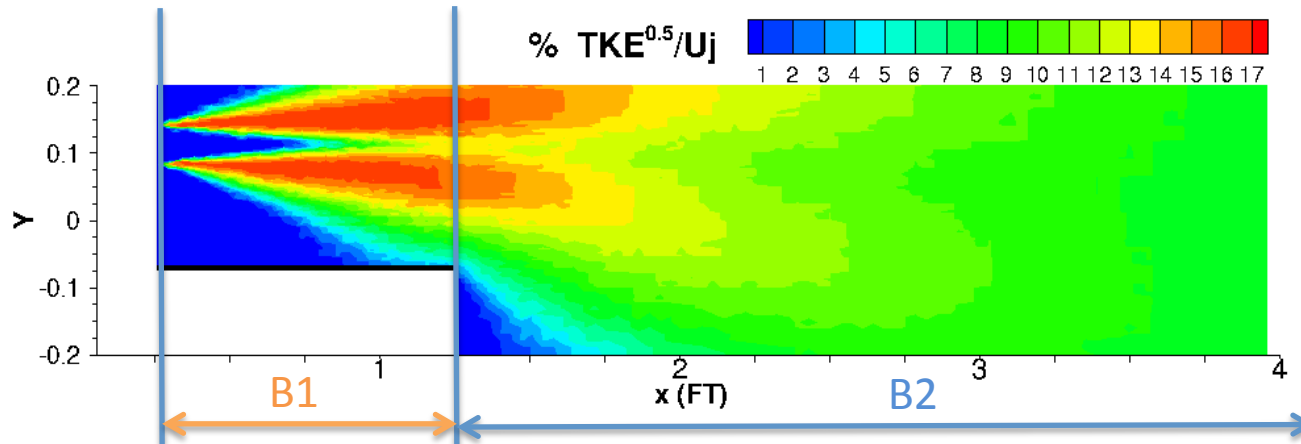
Sample Results (Cont'd)

N8Z – SP07-Isolated

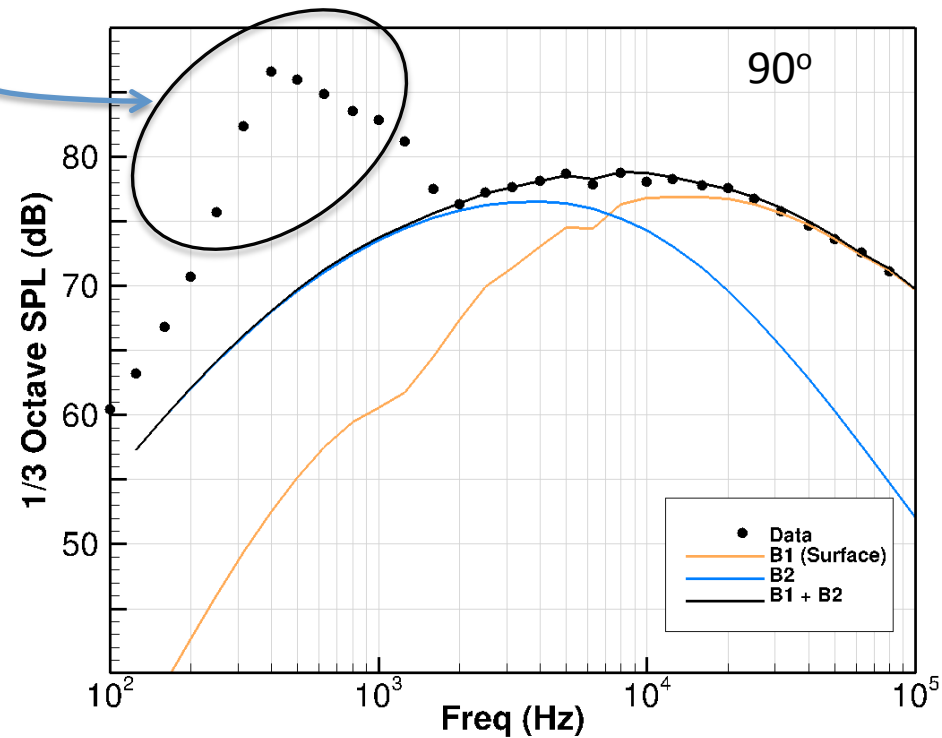


Sample Results (Cont'd)

N8Z – SP05-H19-XTE12

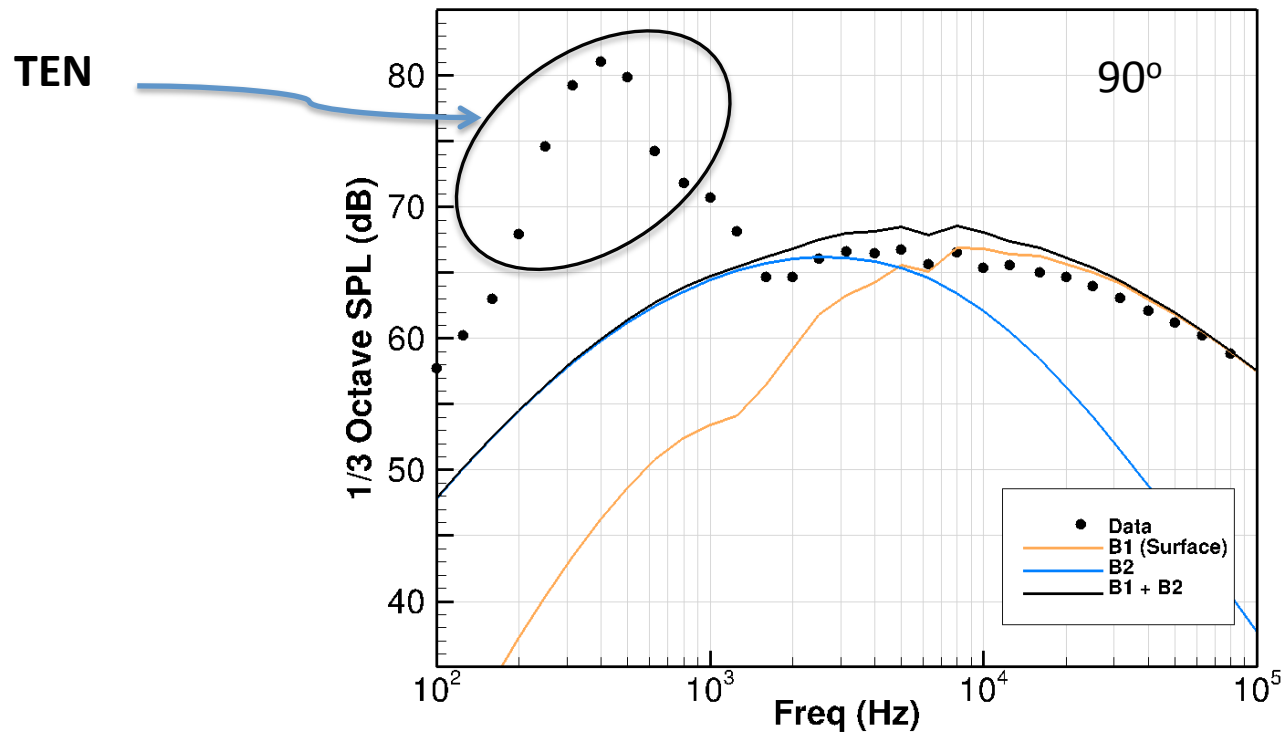
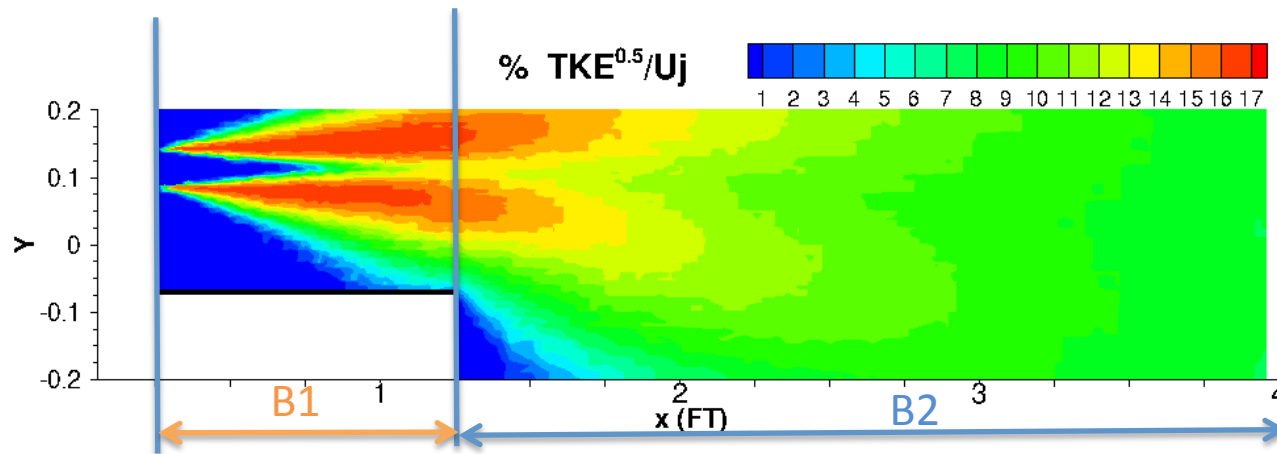


TEN



Sample Results (Cont'd)

N8Z – SP03-H19-XTE12





Summary

- The GF was evaluated using RANS input (SolidWorks)
- The mean flow was considered as locally parallel in two directions (HAR rectangular jets)
- Source calibration parameters (length- and time-scales) follow the usual method (TKE and ε) in a RANS-based Acoustic Analogy.
- Spectral component associated with scrubbing noise dominated at HF
- Jet plume downstream of the TE contributed to low- to mid-frequency
- Trailing Edge Noise (TEN) should be superimposed on present predictions.

Next Step

- Consistency across operating conditions requires mean flow and turbulence validation (data and/or alternative RANS solvers)
- Heated jets (enthalpy-related source).



QUESTIONS ?